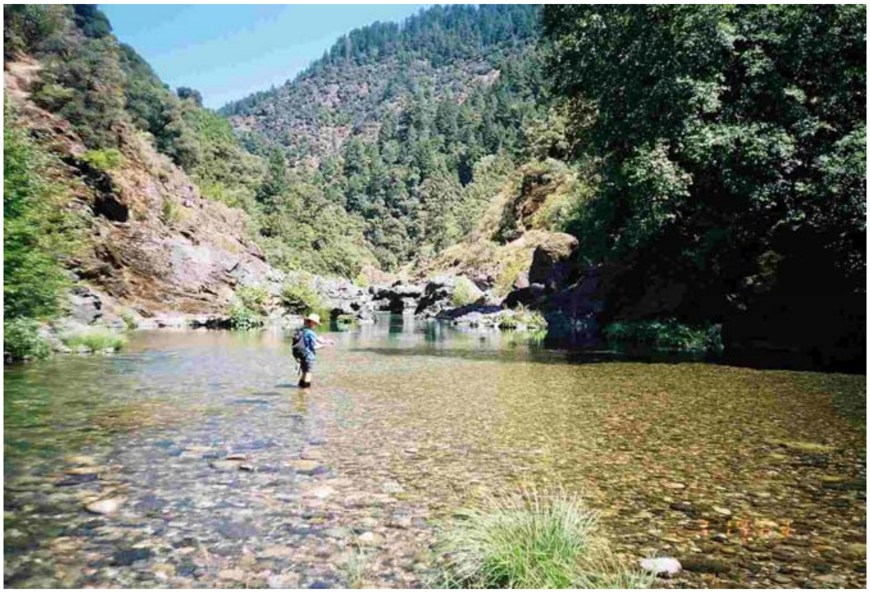
APPENDIX E

Upper Yuba River Chinook Salmon and Steelhead Rearing Habitat Assessment



Upper Yuba River
Chinook Salmon and Steelhead Rearing Habitat Assessment

Technical Appendix

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1 INTRODUCTION AND BACKGROUND

The Upper Yuba River Studies Program seeks to determine the feasibility of introducing wild Chinook salmon and steelhead into the upper Yuba River upstream of Engelbright Dam. One objective of the evaluation is to determine the suitability of aquatic habitat in the upper river and its ability to support salmon and steelhead under current operations and under other potential operation scenarios. The quantity and quality of rearing habitat will be an important factor in that evaluation. This report describes the habitat needs of these species during their fresh water rearing life history stage, the methods used to assess rearing habitat under current conditions, and the results of the assessment.

1.1 Life History of Fry and Juvenile Chinook Salmon and Steelhead

Anadromous salmonids require a suite of habitat characteristics for successful rearing in fresh water. Many of these characteristics can vary in importance depending on the species, life history type (run), and season. Spring-run Chinook salmon were historically present in the Yuba River (Yoshiyama et al. 2001) and currently occur in the lower Yuba River below Engelbright Dam. This assessment is therefore focused on the spring-run life history type. Life history strategies and timing of rearing spring-run Chinook salmon and steelhead are summarized below. Rearing habitat characteristics are described in Section 2.

1.1.1 Chinook salmon

Spring-run Chinook salmon (*Oncorhynchus tshawytscha*) fry in the Sacramento River basin generally emerge from the gravels between November and March (Fisher 1994, Ward and McReynolds 2001). Spring-run Chinook salmon typically spend up to one year rearing in fresh water before migrating to sea, but the length of time spent rearing in freshwater also varies greatly. Juvenile Chinook may disperse downstream as fry soon after emergence; early in their first summer as fingerlings; in the fall as flows increase; or after overwintering in freshwater as yearlings (Healey 1991). Even in rivers such as the Sacramento River, where many juveniles rear until they are yearlings, some juveniles probably migrate downstream throughout the year (Nicholas and Hankin 1989). Although fry typically drift downstream following emergence (Healey 1991), movement upstream or into cooler tributaries following emergence has also been observed in some systems (Lindsay *et al.* 1986, Taylor and Larkin 1986). Juvenile Chinook rearing densities vary widely according to habitat conditions, presence of competitors, and life history strategies (Lister and Genoe 1970; Everest and Chapman 1972; Bjornn 1978, as cited in Bjornn and Reiser 1991; Hillman *et al.* 1987).

Unlike rearing fall-run Chinook salmon which are present in streams only in winter and spring when flows are generally highest and water temperatures lowest, rearing spring-run Chinook may be subject to summer conditions such as high water temperatures and reduced habitat availability resulting from increased solar radiation, warmer weather, and lower summer flows. Nicholas and Hankin (1989) suggest that the duration of freshwater rearing is tied to water temperature, with juveniles remaining longer in rivers with cool water temperatures, such as the North Umpqua River, Oregon.

1.1.2 Steelhead

Steelhead is the term commonly used for the anadromous life history form of rainbow trout (*Oncorhynchus mykiss*). Steelhead exhibit highly variable life history patterns throughout their range, but are broadly categorized into winter and summer reproductive ecotypes. Winter steelhead, the most widespread reproductive ecotype, become sexually mature in the ocean, enter spawning streams in summer, fall or winter, and spawn a few months later in winter or late spring (Meehan and Bjornn 1991, Behnke 1992). Only winter-run steelhead stocks are currently present in Central Valley streams (McEwan and Jackson 1996). Unlike Pacific salmon, adult steelhead may return to the ocean after spawning and return to freshwater to spawn in subsequent years.

Juveniles typically remain in fresh water for 2–4 years before emigrating to the ocean from April–June (Barnhart 1991). In the Sacramento River, steelhead generally emigrate as 2-year olds during spring and early summer months (McEwan and Jackson 1996). Emigration appears to be more closely associated with size than age, with 6–8 inches (152–203 mm) being the most common length for downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds *et al.* 1993). Rearing steelhead, like spring-run Chinook salmon, therefore experience low flow conditions during summer and must contend with factors such as increased water temperature and reduced habitat area during summer that may reduce the quantity and/or quality of fresh water rearing habitat.

Research has shown that although age 1+ smolts may compose a substantial portion of outmigrating steelhead, their survival is poor and they often contribute little to the numbers of returning adults (Shapovalov and Taft 1954, Kabel and German 1967). Survival of steelhead smolts tends to be much greater if outmigration occurs at age 2+ or 3+. Steelhead migrating downstream as juveniles may rear for one month to a year in the estuary before entering the ocean (Barnhart 1991), and the growth that takes place in estuaries may be very important for increasing the odds of marine survival (Smith 1990, McEwan and Jackson 1996). Persistence of a steelhead population is therefore highly dependent on the quantity and quality of habitat for older age classes of juvenile fish (*i.e.*, age 2+ and, to a lesser extent, 3+ and 4+). Because larger fish have greater requirements for space and other resources, however, habitat for age 1+ and older fish is usually more limited than for age 0+ fish.

2 KEY HABITAT CHARACTERISTICS

Physical habitat characteristics believed to be of primary importance (*i.e.*, "key" habitat characteristics) for rearing Chinook salmon and steelhead are summarized briefly below. These habitat characteristics are those for which quantitative river-wide assessments were conducted. The rearing habitat assessment approach, including methods and results, is discussed in Section 3.

2.1 Habitat Type

Habitat preferences of rearing Chinook salmon and steelhead change as fish grow and become more powerful swimmers. Newly-emerged Chinook salmon fry occupy low velocity, shallow water areas near stream margins, including backwater eddies, side channels, and areas associated with bank cover such as large woody debris (LWD) (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). After emergence, steelhead fry move to shallow water, low velocity habitats such as stream margins and low gradient riffles, and will forage in open areas lacking instream cover (Hartman 1965, Everest *et al.* 1986, Fontaine 1988). As they grow, young of both species are able to utilize faster and deeper water, broadening the range of habitats they can occupy. As Chinook salmon fry increase in size and their swimming abilities improve in late summer and fall, they increasingly use areas with cover and show a preference for higher velocity, deeper mid-channel areas (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). Age 0+ steelhead have been found to be relatively abundant in backwater pools and in the downstream ends of pools in late summer (Bisson *et al.* 1988, Fontaine 1988). Steelhead fry may also be found in low gradient riffles.

Pools and other locations with deep, cool water are generally expected to provide preferred summer habitat for rearing Chinook salmon and steelhead. Juvenile Chinook salmon appear to prefer pools that have cover provided by banks, overhanging vegetation, large substrates, or LWD. Juvenile Chinook salmon densities in pools have been found to increase with increasing amounts of cover (Steward and Bjornn 1987). Water temperature may also influence juvenile habitat use. In the South Umpqua River basin, Oregon, Roper *et al.* (1994) observed lower densities of juvenile Chinook where water temperatures were higher. In areas where more suitable water temperatures were available, juvenile Chinook salmon abundance appeared to be tied to pool availability.

As steelhead grow larger, they tend to prefer microhabitats (or "focal points") with deeper water and higher velocity, attempting to find areas with an optimal balance of food supply and energy expenditure, such as velocity refuge positions associated with boulders or other large roughness elements close to fast current areas with high invertebrate drift rates (Everest and Chapman 1972, Bisson *et al.* 1988, Fausch 1993). Age 1+ steelhead typically feed in pools, and appear to avoid secondary channels and dammed pools, glides, and shallow riffles (Fontaine 1988, Bisson *et al.* 1988, Dambacher 1991). Age 1+ steelhead prefer high velocity pool heads (where food resources are abundant) and pool tails (which provide optimal feeding conditions in summer due to lower energy expenditure requirements than the more turbulent pool heads) (Reedy 1995). During the winter period of inactivity, steelhead prefer pool habitats with cover, especially low velocity, deeper pools, including backwater and dammed pools (Hartman 1965, Swales *et al.* 1986, Raleigh *et al.* 1984, Fontaine 1988).

2.2 Substrate

The shallow, low-velocity habitats used by newly emerged Chinook salmon and steelhead fry are generally characterized by finer substrates such as silt and sand. Everest and Chapman (1972) found that spring-run Chinook salmon fry appeared to be most closely associated with substrates ranging in size from silt to 20-cm diameter rubble, with the highest fry densities observed over silt and sand. As they grow, juveniles of both species occur more commonly in association with larger substrates such as gravel, cobble, and boulders.

Chinook salmon and steelhead parr (age 1+) seek out larger substrates and may use clast interstices as resting areas during periods of inactivity and as refuge from high flows. During periods of low temperatures and high flows associated with the winter months, age 0+ steelhead tend to reside in rubble substrates (4–10 inch [10–25 cm] diameter) in shallow, low velocity areas near the stream margin (Bustard and Narver 1975). Overwintering juvenile Chinook salmon appear to use deep pools with LWD and interstitial habitat provided by boulders and cobble substrate (Healey 1991, Swales *et al.* 1986, Levings and Lauzier 1991). Hillman *et al.* (1987) found that the addition of cobble substrate to glide areas in the fall substantially increases winter rearing densities in these areas, with Chinook appearing to prefer interstitial spaces between the cobbles as cover.

Embeddedness by fine sediments may reduce the value of gravel and cobble substrate as winter cover, potentially forcing juvenile Chinook to migrate elsewhere in search of winter cover (Hillman *et al.* 1987, Stuehrenberg 1975). Stuehrenberg (1975) found that juvenile Chinook salmon were displaced when sediment filled gravel interstices. Large sediment particles (cobbles and boulders) are also used as 'home stones' providing refuge from the flow during drift feeding (Morantz *et al.* 1987).

2.3 Cover

Instream and overhead cover are important to rearing Chinook salmon and steelhead during all freshwater life stages and all seasons. As fry, Chinook and steelhead in near-shore areas rely on overhanging vegetation, LWD and other bank cover to reduce the risk of predation. A CDFG study conducted in the upper Sacramento River found that Chinook salmon fry and juveniles are commonly found in areas with both overhead and instream cover (Brown 1990, as cited in Fris and DeHaven 1993). Steelhead fry, however, appear to be somewhat less dependent on cover than Chinook salmon fry, and may forage in areas that lack cover (Hartman 1965, Everest *et al.* 1986, Fontaine 1988). During summer, juveniles of both species are closely associated with overhead and complex instream cover, including overhanging vegetation, undercut banks, LWD, and large substrates. During the warmer parts of the year, steelhead parr appear to prefer habitats with cover provided by rocky substrates, overhead cover, and low light intensities (Hartman 1965, Facchin and Slaney 1977, Ward and Slaney 1979, Fausch 1993).

In winter, rearing Chinook salmon and steelhead seek areas with low water velocities and instream cover, such as well-vegetated, undercut banks, deep pools with LWD, and interstitial habitat provided by boulders and cobble substrate. Hillman *et al.* (1987) found that juvenile Chinook salmon remaining in tributaries to overwinter chose areas with cover and low water velocities, such as areas along well-vegetated, undercut banks. During the winter period, age 1+ steelhead use interstices between assemblages of large boulders (>39 in [100 cm] diameter), logs, and/or rootwads as winter cover (Bustard and Narver 1975, Everest *et al.* 1986).

2.4 Large Woody Debris

Large woody debris can be a key habitat component for rearing salmonids throughout their fresh water residence. Large woody debris exerts a strong control on channel morphology and provides refuge from predation and high flows. The distribution and abundance of juvenile salmonids in streams has often been shown to be positively correlated with the quantity and quality of woody cover. Steward and Bjornn 1987) found that the amount of woody debris was among the most important factors influencing density of juvenile Chinook salmon and steelhead in experimental pools. Although steelhead have generally been found to prefer large substrates (*i.e.*, boulder and cobble) or other features as cover, age 1+ steelhead will also use logs, and/or rootwads as winter cover (Bustard and Narver 1975, Everest *et al.* 1986).

In addition to providing cover, LWD also traps and stores sediment, thereby influencing channel morphology and the configuration and distribution of habitat for rearing salmonids. By storing sediment, LWD exerts an important local control on channel morphology (Montgomery and Buffington 1997). Generally, the influence of LWD increases morphological heterogeneity, providing greater hydraulic and sedimentary complexity and, therefore, habitat diversity.

2.5 Riparian Vegetation

Riparian vegetation provides overhead cover for rearing salmonids and, by shading the channel, helps reduce incident solar radiation and maintain cool water temperatures (Beschta *et al.* 1987, Poole 2002). Organic input from leaf litter fall and woody debris also serves as an important source of nutrients for the river food web (Gregory *et al.* 1991, Naiman *et al.* 1992). Many of the aquatic invertebrates used as food by rearing Chinook salmon and steelhead are dependent on nutrients derived from riparian vegetation. The importance of riparian vegetation for rearing Chinook and steelhead is undoubtedly greatest in spring and summer, when vegetation biomass is highest and the leaves of deciduous riparian trees provide shade and increased overhead cover for vulnerable fry and juveniles.

2.6 Channel Confinement

The degree to which a river channel is constrained within the walls of its valley, or channel confinement, can be an important determinant of the amount of off-channel or floodplain habitat available to rearing salmonid fry. Confined channels have little or no room on the valley bottom to form lateral meanders and are therefore relatively straight, generally paralleling the valley walls. Since lateral confinement produces relatively high bed slopes (due to low sinuosity) and minimal floodplain area to dissipate the energy of overbank flows, water velocity is higher during floods compared to unconfined valleys. The resultant high transport capacity exhibited by such channels tends to produce plane bed and step-pool morphologies that are characterized by coarser sediments (Montgomery and Buffington 1997). Therefore, there are fewer of the high quality backwater and side channel habitats preferred by salmonid fry. Salmonids rearing in confined channels are subject to scour and displacement during high flows if velocity refugia are not available. However, cobble- and boulder-sized sediments provide important rearing, sheltering and overwintering for the parr (age 1+) life stage (Bustard and Narver 1975, Coulombe-Pontbriand and Lapointe 2004).

In addition to the above physical habitat characteristics, several other factors may have an important influence on the success of rearing salmon and steelhead. These factors are addressed separately below.

In addition to physical habitat characteristics, a number of other factors influence the quality of habitat and fresh water rearing success of anadromous salmonids. Several of these factors, considered to be of potential importance to rearing Chinook salmon and steelhead in the Upper Yuba River study area, are summarized below.

2.7 Water Temperature

Salmonids have relatively narrow temperature tolerances during rearing. Although fish may survive water temperature extremes, altered metabolic processes at high and low temperatures result in reduced growth. Water temperatures in streams can fluctuate widely on both a seasonal and daily basis, especially in streams with little shade and/or low summer flows. In the Upper Yuba River basin, it is likely that high water temperatures are a key limiting factor for salmonids during summer/fall rearing, primarily because of streamflow regulation, lack of riparian shade, and ambient temperature conditions in summer and fall. Water temperature may also be an important determinant of juvenile habitat use. In the South Umpqua River basin, Oregon, Roper *et al.* (1994) observed lower densities of juvenile Chinook salmon where water temperatures were higher. In areas where more suitable water temperatures were available, juvenile Chinook salmon abundance appeared to be tied to pool availability. Water temperature can exert strong influence on the amount of usable summer rearing habitat for Chinook salmon and steelhead in the Upper Yuba River basin.

Temperatures also have a significant effect on juvenile growth rates. On maximum daily rations, growth rate increases with temperature to a certain point and then declines with further increases. Reduced rations can also result in reduced growth rates; therefore, declines in juvenile salmonid growth rates are a function of both temperature and food availability.

Juvenile Central Valley spring-run Chinook salmon prefer rearing temperatures around 60°F (15.6°C) (NOAA 2002, as cited in CDWR 2004), with a reported range for optimum growth of 56–60°F (13.2–15.3°C) for American River Chinook salmon (Rich 1987, FERC 1993). Depending on acclimation temperature, the upper incipient lethal temperature for Chinook salmon of Sacramento River origin reportedly ranges from 75–84°F (24–28.8°C) (Rich 1987, Hanson 1991, Cech and Myrick 1999, Myrick and Cech 2001). The upper lethal temperature is dependent on the temperature to which fish are already acclimated, and will increase—up to a certain point—as fish are acclimated to increasingly higher temperatures.

Rearing steelhead can apparently tolerate slightly higher temperatures than Chinook salmon. Myrick and Cech (2000, as cited in Myrick and Cech 2001) report a preferred rearing temperature of 63°F (17°C) for Central Valley steelhead (wild Feather River fish). Temperatures for optimum growth and development of juvenile steelhead, based on laboratory studies, range from 59–66°F (15–19°C) (Myrick and Cech 2001). Temperatures >77°F (25°C) are reportedly lethal to juvenile Central Valley steelhead (Myrick and Cech 2001, FERC 1993).

2.8 Water Quality

Besides water temperature, a variety of other water quality parameters can affect the distribution and abundance of rearing salmonids in streams. These include turbidity, dissolved oxygen, nutrients, fertilizers, pesticides, and other toxic chemicals. Some of these parameters, such as dissolved oxygen and toxic chemicals, can directly influence rearing success by causing mortality. Other water quality problems may have indirect impacts on rearing success by reducing habitat quality or the availability of food resources. Heavy metals may also have direct or indirect effects on salmonid rearing success.

Water quality parameters were not assessed as part of the rearing habitat analysis. However, we are not aware of any evidence to indicate that water quality in the Upper Yuba River study area would be problematic for rearing Chinook salmon or steelhead.

2.9 Food Resources

The availability of food is a key requirement for rearing salmonids. Aquatic macroinvertebrates are the primary food consumed by salmonids in streams. Production of aquatic invertebrates depends in large part on the amount of organic material available in the stream food web.

The abundance and diversity of aquatic macroinvertebrates in a stream can be determined only by intensive sampling and analysis. Macroinvertebrate sampling was not conducted as part of the rearing habitat analysis. However, based on preliminary observations of benthic macroinvertebrates made during field surveys, it appears that the abundance and diversity of macroinvertebrates in the South and Middle Yuba rivers is likely to compare favorably with other salmonid streams in northern California.

2.10 Predation

Rearing salmonids are subject to predation during their entire freshwater residence. In river systems where introduced piscivorous fish are abundant, predation pressure on salmonid fry, juveniles, and smolts may be particularly high. In the lower Tuolumne River, introduced predators such as largemouth bass were estimated to contribute to as much as 70% of the mortality of outmigrating juvenile Chinook salmon documented by the California Department of Fish and Game in 1987 (TID/MID 1992).

Fish survey data from the South Yuba River indicate the presence of introduced predatory smallmouth bass, bluegill, and green sunfish downstream of Starvation Bar (Moyle and Gard 1993, FERC 1987, as cited in Moyle and Gard 1993). Largemouth bass were recorded from the South Yuba River by FERC (1987, as cited in Moyle and Gard 1993), but no location information was given for this species and location data were not found by Moyle and Gard (1993). The Northwest Power Company (1983, as cited in Moyle and Gard 1993) reported that smallmouth bass composed 2% of the fish population in sampled portions of the South Yuba River upstream of Hoyt Crossing. In addition to these species, data from the US Army Corps of Engineers (1991, as cited in Moyle and Gard 1993) indicate that Alabama spotted bass, another piscivorous species, were stocked in Englebright Reservoir in 1986. Moyle and Gard (1993) suggest that the persistence of the smallmouth bass population in the South Yuba River depends on immigration from Englebright Reservoir. No fish species composition or distribution data were available for the Middle Yuba River, but it is likely that species composition is similar to the South Yuba

River where similar habitat conditions occur and passage is possible upstream of Englebright Reservoir.

Moyle and Gard (1993) observed that predation by smallmouth bass appeared to be limiting the abundance of native Sacramento pikeminnow and hardhead in the South Yuba River downstream of Starvation Bar. Although it is not possible to quantify the potential effects of predation on anadromous salmonids, it can be assumed that introduced predators would have some impact on outmigrating Chinook salmon and steelhead. However, salmon and steelhead rearing in upstream areas would not likely be subject to substantial predation by introduced piscivores because preferred salmonid rearing habitat is not expected to overlap significantly with habitat used by introduced predators.

2.11 Diversions

Water diversions can impact populations of rearing salmonids both directly and indirectly. Direct impacts include mortality or injury due to entrainment in the diversion or, if the diversion is screened, impingement at the intake screen. Indirect impacts may result from displacement by entrainment as well as habitat loss due to reduced streamflow downstream of the diversion.

There is only one major diversion in the Upper Yuba River study area, located at Our House Dam on the Middle Yuba River upstream of Oregon Creek (approximately 12 miles upstream of the confluence with the North Yuba River). Water pooled behind Our House Dam is diverted through an unscreened intake into the Lohman Ridge tunnel. The Lohman Ridge tunnel has a diversion capacity of 850 cfs. Fish that enter the tunnel will end up in Oregon Creek or New Bullards Bar Reservoir. Mortality rates for entrained fish are unknown, but are expected to be low since there are no physical impediments associated with the tunnel (e.g., screens, pipes, valves, turbines). Despite the low expected mortality, any fish diverted into New Bullards Bar Reservoir will be lost from the Middle Yuba River population. Outmigrating salmonids entrained in the Lohman Ridge tunnel and ending up in New Bullards Bar Reservoir would be prevented from continuing their downstream migration and would not contribute to adult returns. It is possible that fish diverted into Oregon Creek (but not continuing to New Bullards Bar Reservoir) could re-enter the Middle Yuba River and potentially contribute to the Middle Yuba River population. The proportion of entrained fish that might re-enter the Middle Yuba River in this manner is unknown.

3 ASSESSMENT METHODS AND RESULTS

An office-based habitat assessment of the South Yuba and Middle Yuba rivers was performed using color aerial photographs taken on October 16, 2002 and digital aerial video taken during helicopter overflights on October 22, 23, and 24, 2002. The river flows at the time the video was taken were approximately 42 cfs in the South Yuba River at Jones Bar (CDWR Station ID = JBR) and 32 cfs in the Middle Yuba River below Our House Dam (CDWR Station ID = ORH). These flows are typical of low summer baseflows in these rivers (CDEC 2003 [http://cdec.water.ca.gov/ accessed on August 13, 2003]).

ArcGIS software was used to create a line feature representing the channel thalweg on an imported theme consisting of the 1:24,000 scale color aerial photography (Figure 1). Habitat units were determined by visual analysis of the aerial photographs (Figure 1) and video (Figure 2) and the line feature was divided to correspond with unique habitat type classifications.

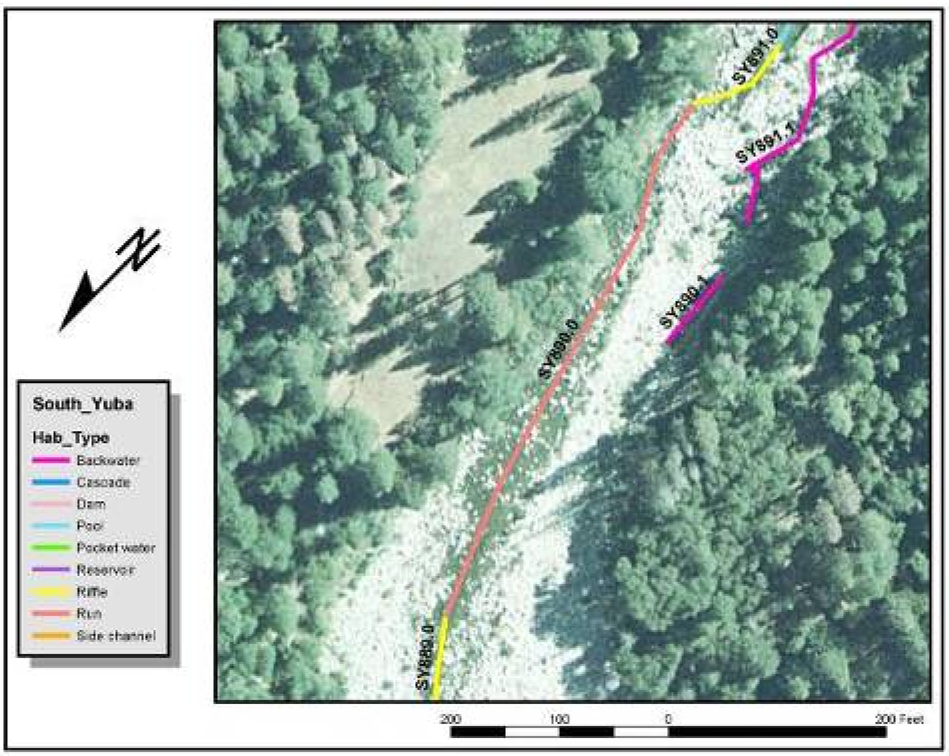

Figure 1. Color aerial photograph showing a portion of the South Yuba River, used as an ArcGIS layer to delineate habitat types and features related to rearing habitat for Chinook salmon and steelhead.

Figure 2. Screen capture from digital overflight video, showing the same South Yuba River habitat unit as in Figure 1. The digital video was used in conjunction with the aerial photographs to perform the office-based rearing habitat assessment.

Habitat types were classified using the system of McCain *et al.* (1990), with simplifications to accommodate the limitations of resolution in the aerial photographs and video. The office-based habitat assessment resulted in approximately 1,100 unique habitat units each for the South Yuba and Middle Yuba rivers. A total of 43.4 miles of mainstem channel was assessed for the South Yuba River and 44.7 miles for the Middle Yuba River, representing over 98% of the total channel length of each river. Small portions of the channel in each river immediately downstream of the dams (Milton Dam on the Middle Yuba and Lake Spaulding Dam on the South Yuba) were not assessed due to missing or poor quality photo or video coverage.

Each habitat unit was numbered consecutively in an upstream direction using a decimal system to differentiate secondary channels and backwaters from the main channel (Figure 1). For each habitat unit, 20 separate attributes were recorded (Table 1), the majority of which relate to habitat features considered important to rearing anadromous salmonids. Non-habitat attributes such as landmarks and access points were noted to assist with orientation. The accuracy of the office based habitat assessment was limited by the inherent resolution and image quality of the source data.

Table 1. Attributes assessed for each channel segment (unit), based on aerial photo and video analysis.

Attribute	Description
Unit number	Channel segment number, numbered consecutively in an upstream direction
Habitat type	Selected habitat types, modified from McCain *et al.* (1990): backwater, cascade, pocket water, pool, riffle, run.
Substrate	Dominant and subdominant bed substrate type (fine, gravel, cobble, boulder, bedrock)
Channel confinement	Ratio of width of active channel to valley width (confined = valley width/channel width ≤ 2; not confined = valley width/channel width > 2)
LWD	Number of large woody debris pieces in the unit
LWD length	Number of large woody debris pieces in each of three length categories (< 0.5 channel widths; 0.5-1.0 channel widths; >1.0 channel widths)
LWD in active channel	Number of large woody debris pieces located within the active channel
Deep	Water depth in unit appears >3-5 ft
Deep pool max width	Maximum width of pools with depth >3-5 ft
Cover amount	Total amount of cover in unit, reported in quartiles
Cover type	Dominant and subdominant cover types in unit
Riparian vegetation length	Percentage of bank length with riparian vegetation, reported in quartiles
Riparian vegetation width	Width of riparian vegetation on each bank, reported as a ratio of channel width
Shade	Amount of water's surface obscured from visibility from above by riparian vegetation or other feature, reported in quartiles
Stranding risk	Relative risk of stranding or entrapment in the unit as a whole (0 = none, L = low, M = moderate, H = high)
Stranding Type	Description and location of the predominant physical feature(s) likely to cause stranding or entrapment
Diversion	Description and location of any potential water diversions in the unit
Barrier	Description and location of any potential barrier to upstream or downstream fish migration
Access	Description and location of any potential access to the unit
Landmarks	Description and location of any feature that might provide a location reference point

To compare remotely-assessed habitat features with actual field conditions, ground truthing surveys were performed at selected locations in the South and Middle Yuba rivers (Figure 3). Five reaches, each of approximately one mile in length, were surveyed in each of the South and Middle Yuba rivers during ground truthing, representing approximately 11% of the length of each river in the study area. Locations of the ground truthing survey reaches were selected to characterize the upstream to downstream continuum of juvenile salmonid rearing habitat in the watershed, with additional considerations of accessibility by field crews. Ground surveys were conducted by crews of two biologists during July 2003 using standard habitat typing methods based on McCain *et al.* (1990). Additional data collection (*e.g.*, LWD characteristics, channel confinement, stranding) was conducted for comparison with the remote (photo and video) assessment.

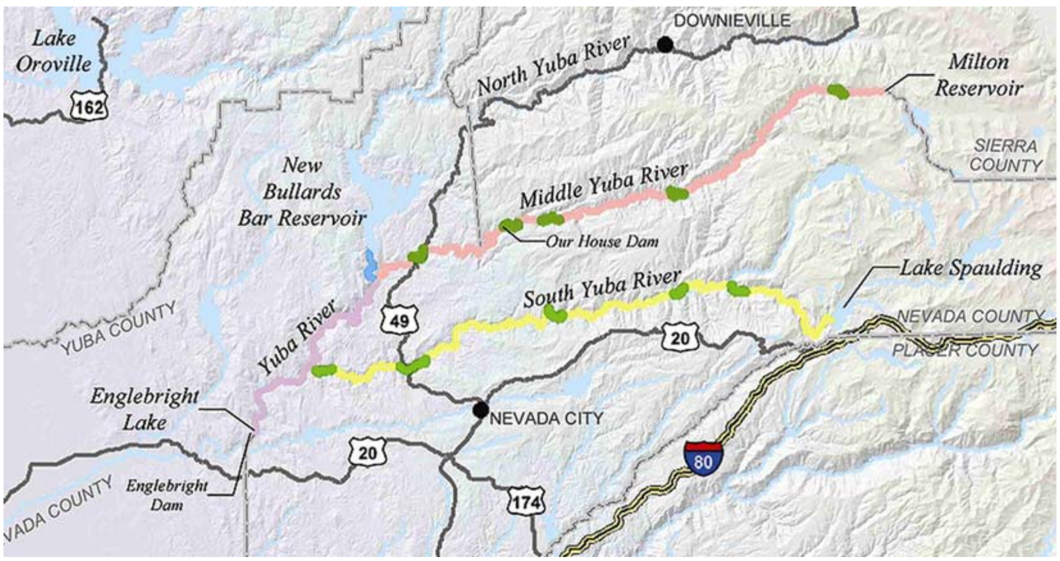

Figure 3. Rearing habitat ground truthing survey reaches in the Upper Yuba River watershed.

3.1 Physical Habitat

3.1.1 Habitat type

The proportion by length of each of the five mainstem habitat types delineated by photo and video analysis is similar in the South and Middle Yuba rivers (Figure 4). Only the length of runs differs appreciably between the two rivers, with 5% more run habitat by length in the Middle Yuba River than in the South Yuba River. Pools compose the majority of habitat by length, representing approximately 45% of the total mainstem channel length in both the South and Middle Yuba rivers. Cascade and pocket water habitats each constitute less than 2% by length of the habitat in both rivers.

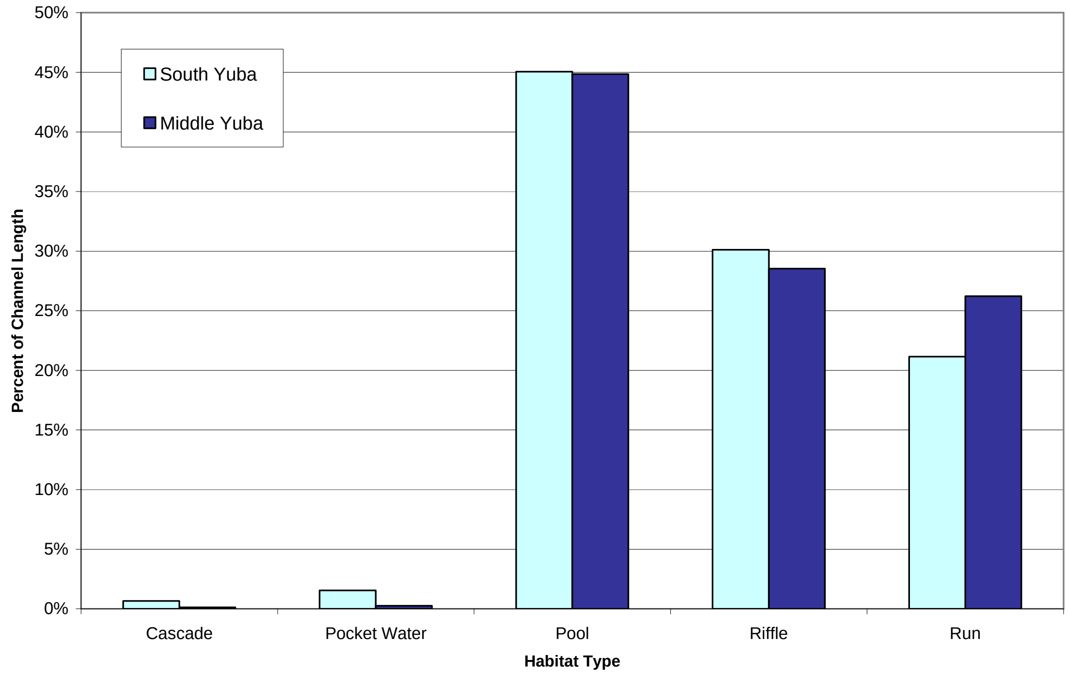

Figure 4. Frequency by length of South and Middle Yuba river main channel habitat types delineated by aerial photo and video analysis.

Off-channel habitats such as backwaters and secondary channels provide important rearing areas for salmonid fry, and may also serve as velocity refugia for rearing salmonids during high winter and spring flows (Figure 5). However, fish using off-channel habitats, especially secondary channels, are subject to stranding as flows recede and these areas are cut off from the main channel.

Figure 5. Off-channel habitat, such as this backwater located on the Middle Yuba River, serves as important rearing and refuge habitat for young salmon and steelhead.

Off-channel habitats are not included in the total main channel habitat length, and were tallied separately. Figure 6 shows the distribution of off-channel habitat by 5-mile increments along the mainstem South and Middle Yuba rivers. The majority of the off-channel habitat in the South Yuba River is located in the upper half of the drainage. The 5-mile segment of the South Yuba River with the greatest length of off-channel habitat (1.5 miles) is located between 30 and 35 miles upstream of Englebright Reservoir. In the Middle Yuba River, off-channel habitat is somewhat more evenly distributed along the length of the river. Proportions between the South and Middle Yuba Rivers are similar between river miles 20 and 35. Two 5-mile segments, located 5–10 miles and 30–35 miles upstream of the confluence with the North Yuba River, contain the greatest amount of off-channel habitat (1.3 miles per segment).

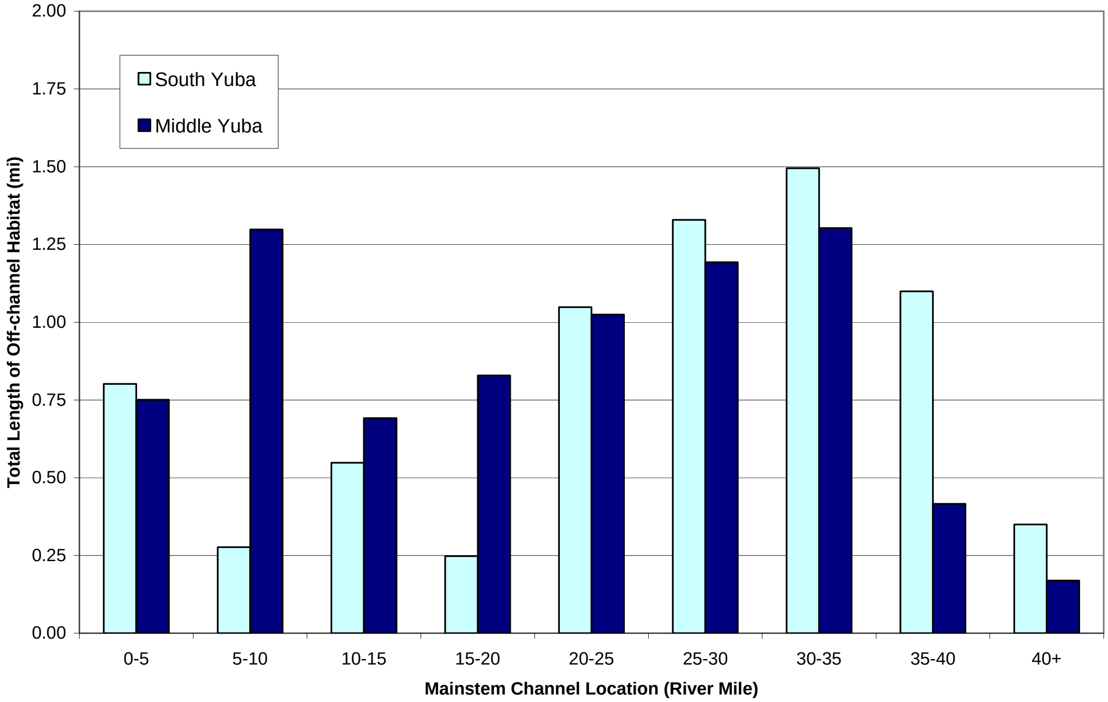

Figure 6. Distribution by length of off-channel habitats in the South and Middle Yuba rivers, as delineated by aerial photo and video analysis.

3.1.2 Substrate

Channel bed substrate types delineated by aerial photo and video analysis were: bedrock, boulder, cobble, gravel, and fines. For purposes of this assessment, sand and finer substrates were classified as fines. Both dominant and subdominant substrate types were recorded as part of the office-based rearing habitat assessment, but only dominant substrates are summarized here.

The channel bed in both the South and Middle Yuba rivers is composed predominantly of boulder substrate, with smaller amounts of bedrock, cobble, gravel, and fines (Figure 7). The frequency by length of most dominant bed substrates is similar in both the South and Middle Yuba rivers. The proportion of boulder and fine substrates, however, differs somewhat between the two rivers. Boulder substrate composes 47% of the dominant substrate by length in the South Yuba River, and 58% in the Middle Yuba River. Fines are roughly three times as prevalent in the South Yuba River, accounting for 16% of the dominant substrate by length in the South Yuba River, but just under 5% in the Middle Yuba River. The proportion by length of cobble and gravel substrate ranges between 10% and 20% in both the South and Middle Yuba rivers. Bedrock is twice as abundant in the South Yuba River, representing 11% of the dominant substrate, compared to 5% in the Middle Yuba River.

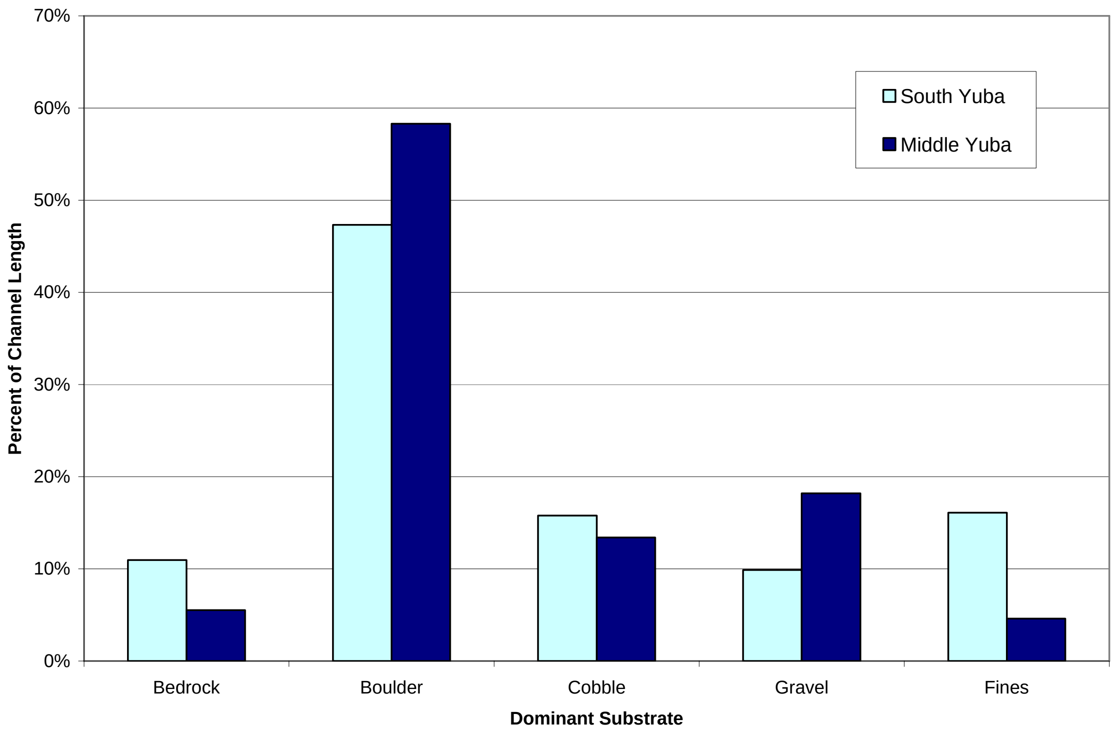

Figure 7. Frequency by length of dominant substrate types in the South and Middle Yuba rivers, based on aerial photo and video analysis.

3.1.3 Cover

The type of cover available to fish was assessed for each habitat unit. Possible cover types were: none, boulder, bedrock ledge, LWD, instream vegetation, overhead vegetation, bubble, and depth. The amount of instream and overhead cover was assessed by estimating the percentage of cover in each habitat unit and assigning a code corresponding to 25% increments (*i.e.*, quartiles).

The amount of cover, as determined by aerial photo and video assessment, is greatest in the Middle Yuba River, with 44% by length of all habitat units having 25–50% cover and 50% by length having 50–75% cover (Figure 8). In the South Yuba River, slightly more than 2% by length of all habitat units were estimated to have no cover. Only 4% of habitat by length in the South Yuba River and 2% in the Middle Yuba River falls in the 75–100% cover category.

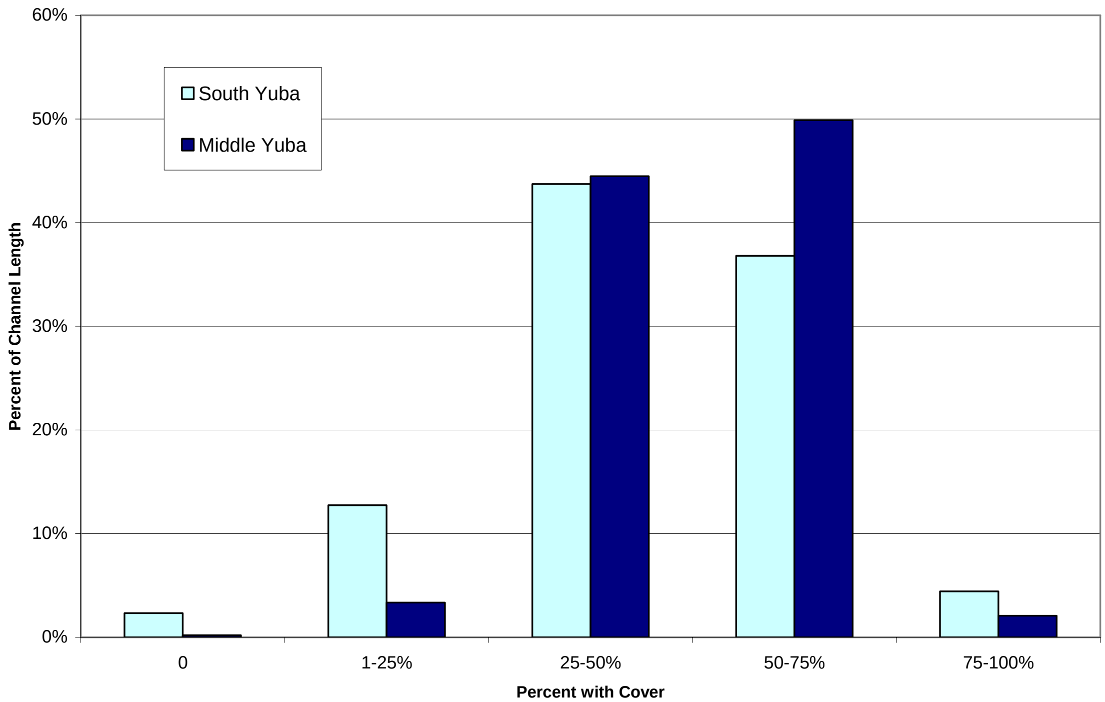

Figure 8. Percentage of total channel length in the South and Middle Yuba rivers in each of five cover classes, based on aerial photo and video analysis.

3.1.4 Large woody debris

Large woody debris abundance was assessed from the aerial photos and video by tallying all LWD visible in each habitat unit. Length of LWD pieces was assessed visually and assigned a length category based on fraction of channel width (< 0.5 channel widths; 0.5-1.0 channel widths; >1.0 channel widths). Because not all LWD is likely to have been visible from the air, this technique may have underestimated LWD abundance. To illustrate the distribution of LWD along the South and Middle Yuba river channels, LWD frequency, reported as the number of pieces of LWD per 1,000 ft, was calculated for each 5-mile increment of channel length.

LWD abundance, as determined by aerial photo and video analysis, is substantially higher in the Middle Yuba River than in the South Yuba River (Figure 9). LWD frequency in the Middle Yuba River ranges from a low of 0.9 pieces/1,000 ft in the first 5 miles of channel upstream of the North Yuba confluence, to a high of 8.9 piecies/1,000 ft in the 5-mile segment located 15–20 miles upstream of the confluence. These values are considerably lower than the range of LWD frequencies reported by Berg *et al.* (1998) for comparable streams in the central Sierra Nevada. Berg *et al.* (1998) measured mean LWD frequencies of 1.2, 14, and 28 pieces/1000 ft in three streams of similar width, gradient, and stream order (Strahler) as the Middle Yuba River. Of 18 stream reaches surveyed by Ruediger and Ward (1996) in the upper Stanislaus River and Tuolumne River drainages, the lowest mean LWD frequency reported was 29 pieces/1,000 ft. LWD frequency determined by our aerial photo and video analysis in the South Yuba River ranges from 0.2 pieces/1,000 ft in the segment located 5 to 10 miles upstream of Englebright Reservoir to 4.3 pieces/1,000 ft in the segment 25 to 30 miles upstream of the reservoir (Figure 9). The majority of the LWD in the South Yuba River is located in upper reaches, more than 25 miles upstream of Englebright Reservoir. In the Middle Yuba River, however, LWD appears concentrated in the middle of the drainage.

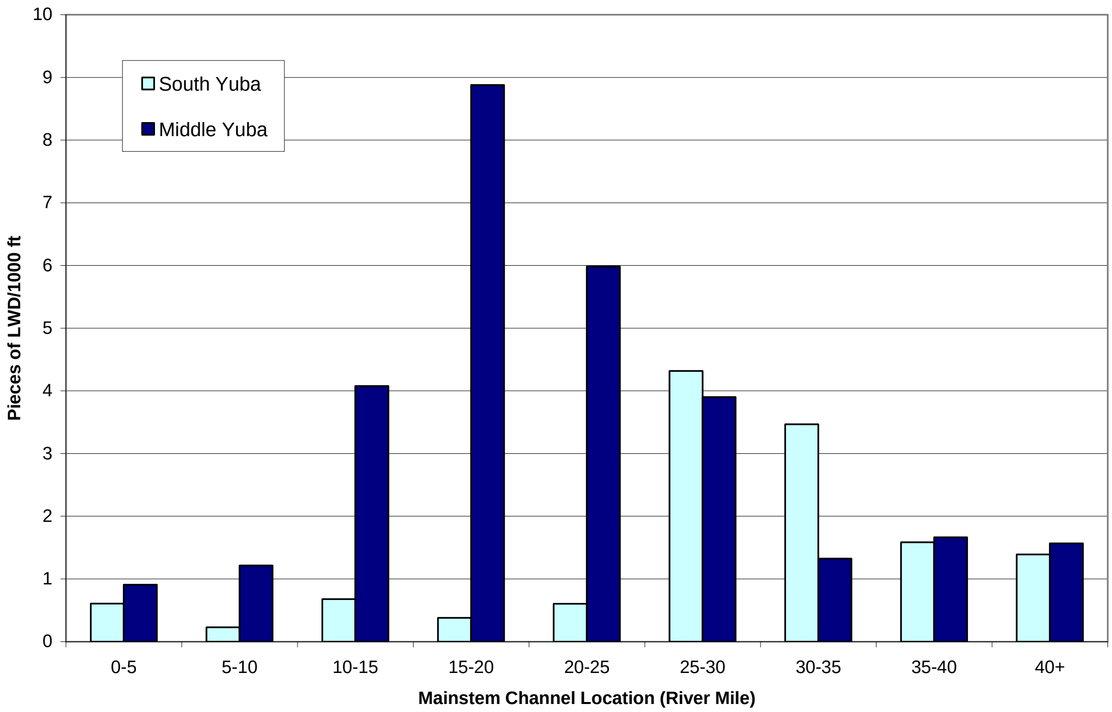

Figure 9. Distribution and abundance of LWD in the South and Middle Yuba rivers, based on aerial photo and video analysis.

3.1.5 Riparian vegetation

The percentage of bank length in each habitat unit with riparian vegetation was estimated for each bank separately by analysis of aerial photos and video and reported in quartiles. The percentage of total bank length in each quartile was derived by summing the vegetated length of each bank in each quartile and dividing by the combined length of both banks. Riparian vegetation was distinguished from non-riparian vegetation primarily by proximity to the river channel. Vegetation growing outside the active channel or above the floodplain (*i.e.*, on the valley walls) was not considered riparian vegetation.

The overall amount of riparian vegetation by length is considerably greater in the Middle Yuba River than in the South Yuba River (Figure 10). In the South Yuba River 55% of the total bank length has no riparian vegetation, whereas 23% of the bank length in the Middle Yuba River is unvegetated. Although the amount of bank length falling into the 1 to 25% vegetation quartile is 25% in both the South and Middle Yuba rivers, the combined bank length in the three highest quartiles is more than twice as great in the Middle Yuba River as in the South Yuba River.

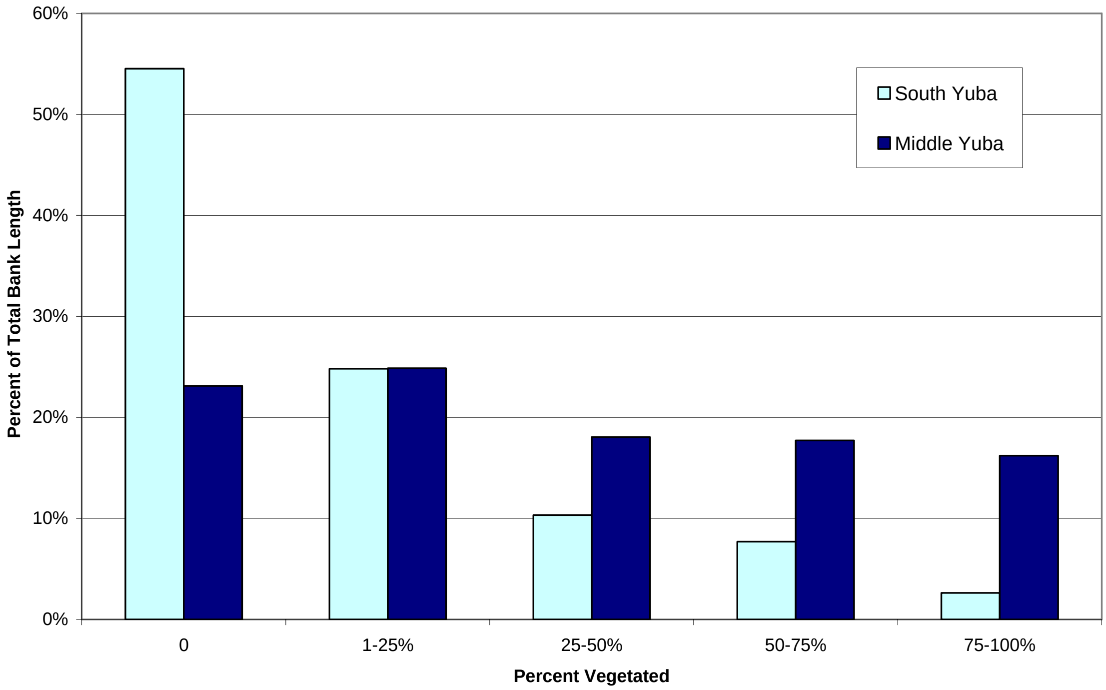

Figure 10. Percentage of the total length of both banks in the South and Middle Yuba rivers in each of five riparian vegetation coverage classes, based on aerial photo and video analysis.

3.1.6 Channel confinement

Channel confinement was assessed from aerial photos and video by comparing the width of the active river channel in each habitat unit with the width of the floodplain (or valley bottom if no floodplain was discernable). A channel was considered confined if the floodplain was less than or equal to twice the width of the active channel. Where the floodplain or valley bottom width was greater than twice the channel width, the channel was classified as not confined.

The channel of both the South and Middle Yuba rivers is almost entirely confined (Figure 11). In the South Yuba River 94% of the total channel length was classified as confined and 6% was considered not confined. In the Middle Yuba River the channel is confined for 96% of its length and only 4% is not confined.

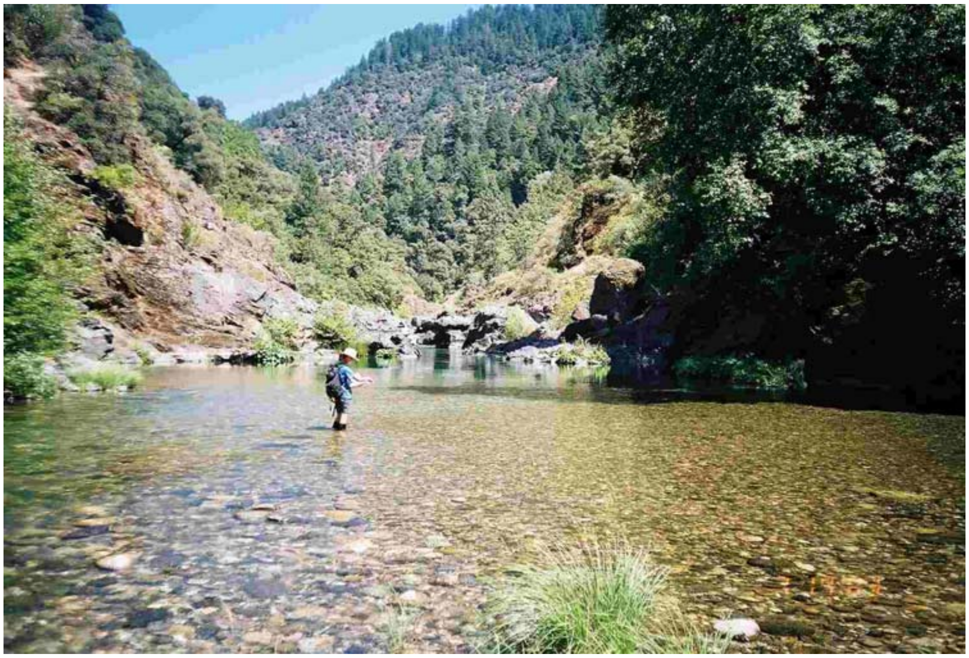

Figure 11. The channel of both the South and Middle Yuba rivers in the assessment area is almost entirely confined within narrow canyon walls.

3.2 Comparison of Remotely-assessed Habitat Characteristics with Ground Truthing Data

3.2.1 Methods

To determine the accuracy of the office-based rearing habitat assessment, data from the aerial photo and video analysis were compared with data collected during the ground truthing field surveys. For each field reach, the data collected using the two analysis techniques were compared and the similarity by length was calculated for the five key physical habitat features discussed above. Similarity values for habitat type, dominant substrate, cover, and riparian vegetation range between 0 and 1, and were calculated using a spherical-distance similarity metric (Small 1996) (see derivation below). The closer the similarity value is to 1, the greater the similarity between remote- and field-collected data. Similarity between remote and field surveyed LWD was assessed using simple comparison of abundance using each method.

Spherical-distance Similarity Metric

This method is used to assess the "similarity" of two values (vectors), disregarding "scale" and "location" differences. That is, we want to treat two vectors $(x_1,\ldots,x_n)$ and $(mx_1+b,\ldots,mx_n+b)$ as equivalent for the purposes of similarity comparisons, for any $m>0$ and any b.

To remove scale and location effects, we replace $\mathbf{x}$ by $\boldsymbol{\tau}$

$$\boldsymbol{\tau} = (\tau_1, \ldots, \tau_n),\ \tau_i = \frac{x_i - \overline{x}}{|\mathbf{x}|},$$

where

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i\ ,\ |\mathbf{x}| = \sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\ .$$

A natural way to compare two such standardized vectors, $\boldsymbol{\tau}$ and $\boldsymbol{\sigma}$ is by the angle between them:

$$\theta(\boldsymbol{\tau}, \boldsymbol{\sigma}) = \arccos(\boldsymbol{\tau} \cdot \boldsymbol{\sigma})$$

where $\boldsymbol{\tau} \cdot \boldsymbol{\sigma}$ is the usual inner product

$$\boldsymbol{\tau} \cdot \boldsymbol{\sigma} = \sum_{i=1}^{n} \tau_i \sigma_i \quad .$$

Standardized vectors can be regarded as points on the n-dimensional sphere; this angle is the same as the great-circle distance between them.

This angle is always between 0 and π, and is 0 when the two (standardized) vectors are identical. For the purposes of this report, it was decided to convert this to a "similarity index" running from 0 to 1, with identical vectors having similarity 1:

$$\text{Similarity}(\boldsymbol{\tau}, \boldsymbol{\sigma}) = 1 - \frac{\theta(\boldsymbol{\tau}, \boldsymbol{\sigma})}{\pi}\ .$$

Putting everything together, and expressing things in terms of the original variables, our final measure of similarity is:

$$\boxed{\text{Similarity}(\mathbf{x}, \mathbf{y}) = 1 - \frac{1}{\pi}\arccos\left(\frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}}\right)}$$

3.2.2 Results

Of all habitat characteristics compared, similarity between the remotely-assessed data and field data was greatest for habitat type, ranging from 0.84 to 0.97 for reaches in the South Yuba River and from 0.87 to 0.97 for reaches in the Middle Yuba River (Table 2). Survey reaches are numbered in Table 2 in an upstream direction, with Reach 1 being the downstream-most reach and Reach 5 the farthest upstream on each river. Agreement was generally highest for habitat type and riparian vegetation, both of which are larger-scale features that could be discerned relatively easily from the aerial photos and video. Smaller-scale features such as substrate, cover, and LWD were naturally more difficult to discern from the aerial photos and video and, as expected, similarity between the remotely-assessed data and field data was lower for these characteristics.

Table 2. Similarity between remotely-assessed habitat characteristics and ground truthing data collected in field survey reaches in the South and Middle Yuba rivers.

River	Reach	Habitat Type	Dominant Substrate	Cover	LWD[1]	Riparian Vegetation
South Yuba	1	0.96	0.77	0.83	0 / 0	0.85
	2	0.84	0.83	0.87	0 / 4	0.85
	3	0.97	0.82	0.73	0 / 11	0.88
	4	0.96	0.77	0.88	0 / 6	0.81
	5	0.95	0.85	0.82	21 / 13	0.79
Middle Yuba	1	0.87	0.83	0.62	4 / 11	0.93
	2	0.89	0.83	0.68	10 / 2	0.86
	3	0.97	0.79	0.85	14 / 15	0.85
	4	0.95	0.91	0.97	25 / 34	0.88
	5	0.94	0.75	0.89	23 / 57	0.95

[1] Similarity for LWD is shown as the number of LWD pieces observed in the reach by each assessment method. The first number is from the aerial photo and video analysis and the second number is from the ground truthing field surveys (*i.e.*, # remote / # field).

In general it appears that the agreement between remotely-assessed rearing habitat data and data collected in the field is adequate to provide a river-wide assessment of the distribution and relative abundance of key habitat characteristics. Reliability of the office-based habitat assessment technique is greater for large-scale features (*i.e.*, macrohabitat characteristics) than for small-scale features (microhabitat), and the remotely assessed data should therefore be interpreted with this in mind. The use of the office-based habitat assessment technique to quantify microhabitat availability or suitability is not recommended.

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